MEMS Standardization: *cif*-MEMS

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COTS MEMS

October 21, 2003
San Francisco, CA

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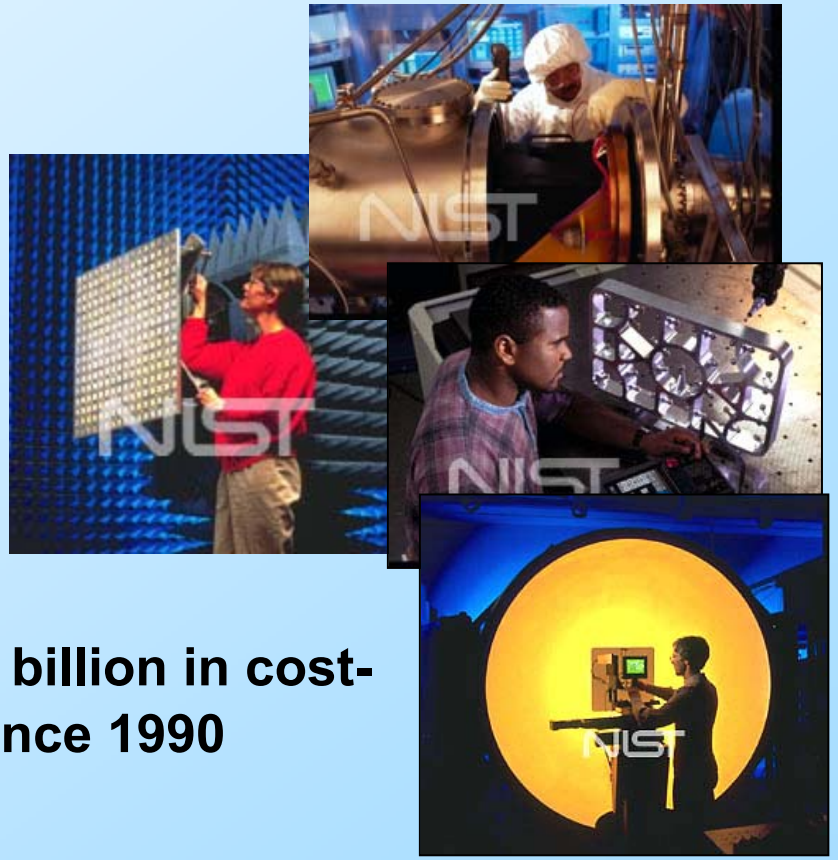
http://mems.nist.gov

NIST

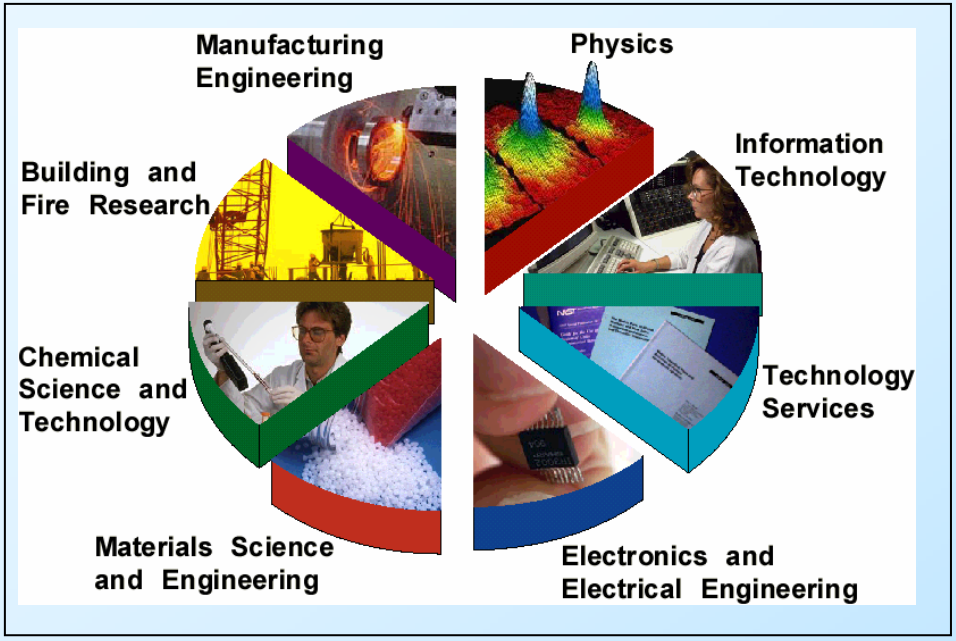
Mission: to develop and promote measurements, standards, and technology to enhance productivity, facilitate trade, and improve the quality of life.

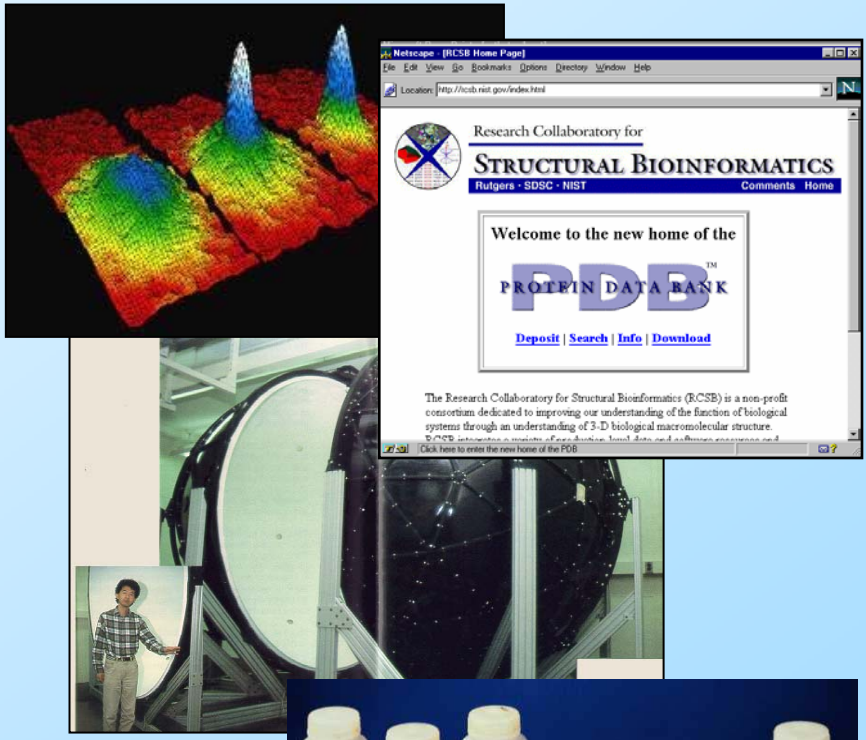


Programs:

- Advanced Technology Program - $4 billion in cost-shared partnerships with industry since 1990
- NIST Laboratories
- Also
  - Manufacturing Extension Partnership MEP
  - Baldrige National Quality Award

NIST Laboratories





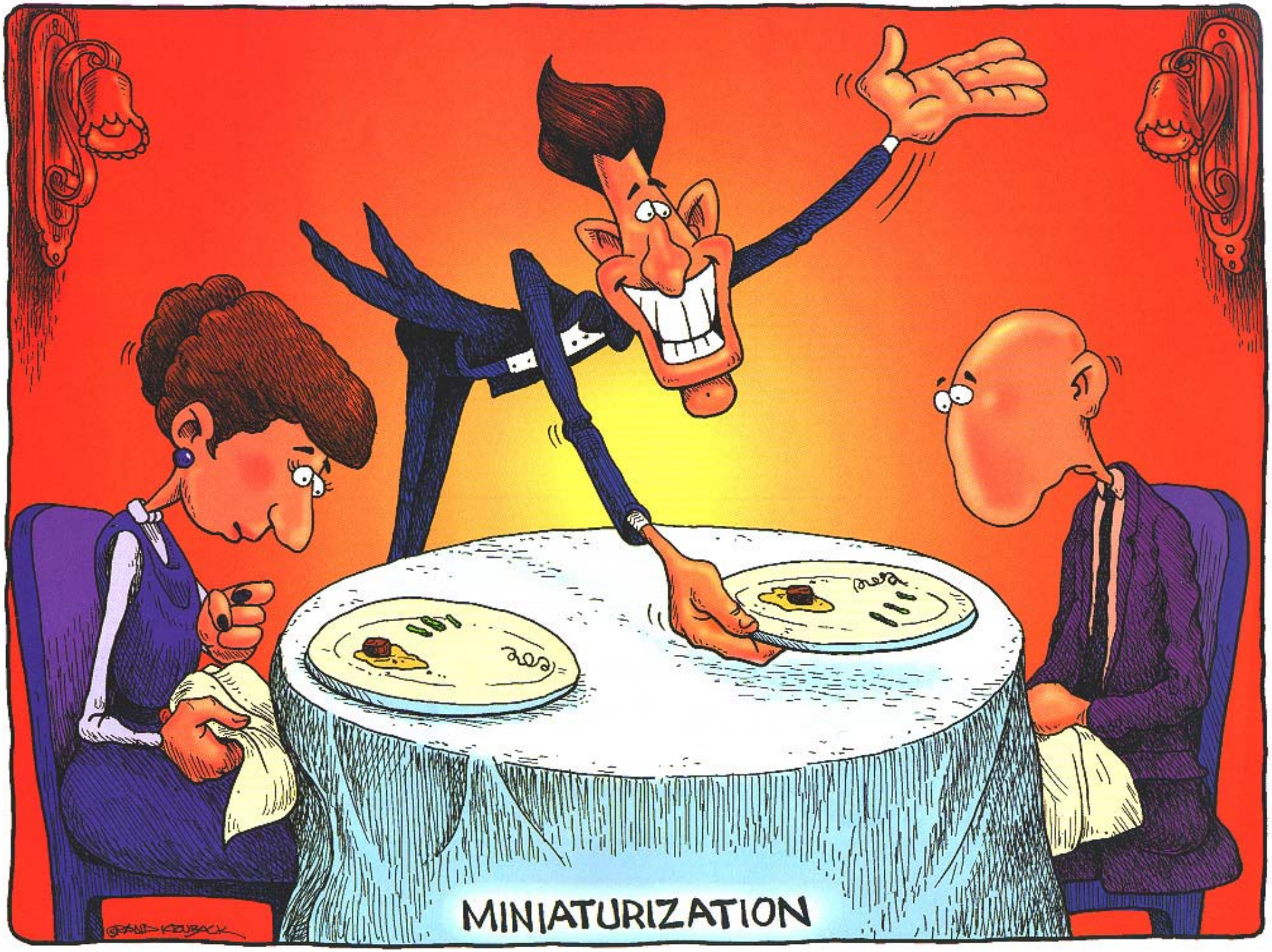
Standard Reference Materials: *1,300 products available*
31,000 units sold/year
Standard Reference Data: 90 types available
5,500 units sold/ year
Calibrations and Tests: *3,000 items calibrated/year*
Laboratory Accreditation: *819 accreditations*
Standards Committees: *440 NIST staff, 970 committees*

Standards for MEMS

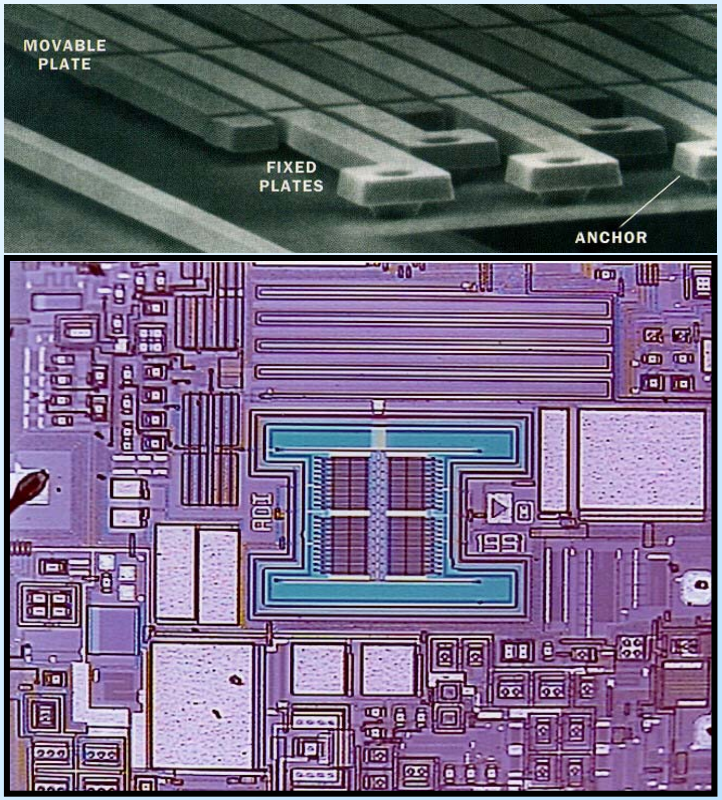
- Developed by consensus
- Types of Standards
  - Measurement Methods
  - Packaging
  - Manufacturing
  - Terminology
- NIST can also provide
  - Standard reference materials
  - Calibrations

Today's Topics

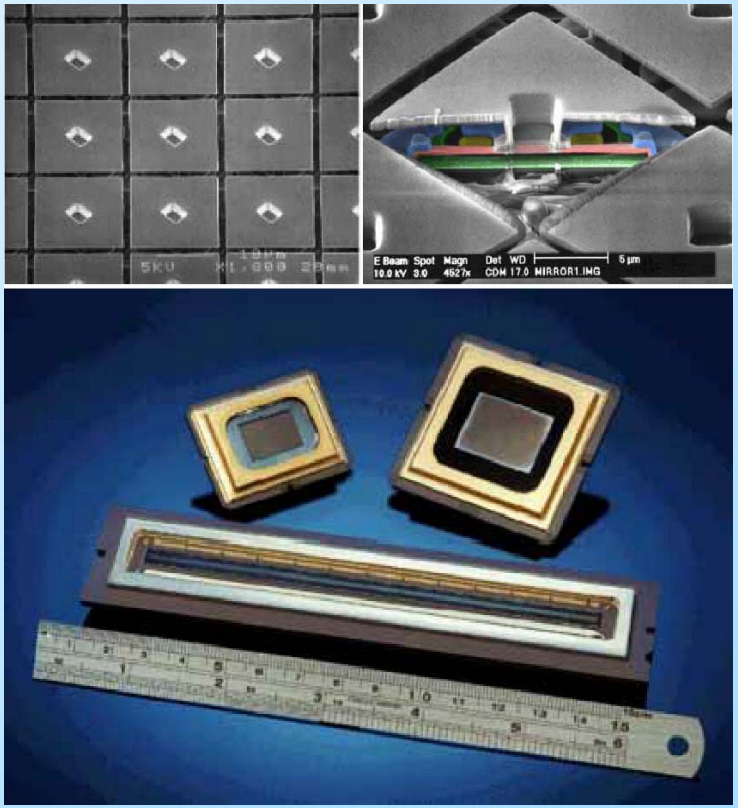
- *cif*-MEMS (*CMOS IC Foundry MEMS*)
  - Introduction
  - Devices
- Standards Activities
  - Test Structures/Standards


MINIATURIZATION

Commercial Examples



Analog Devices Accelerometer



Texas Instruments Deformable Mirror Display

Challenge: How does one integrate MEMS with CMOS ?

Monolithic Integration

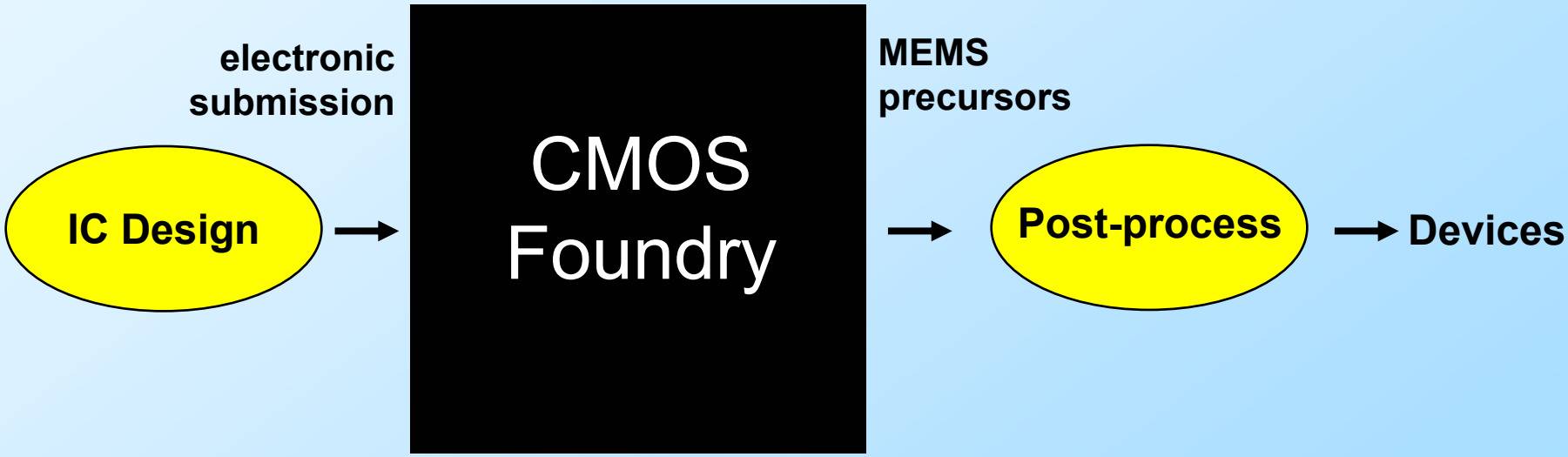
Fabrication of MEMS

- **Full Custom**
  - Ex: BSAC, Stanford Nanofab, …
- **Fabrication House**
  - Ex: ISSYS, Micralyne, MEMS Exchange
- **Foundry**
  - Ex: Cronos (MEMSCAP)

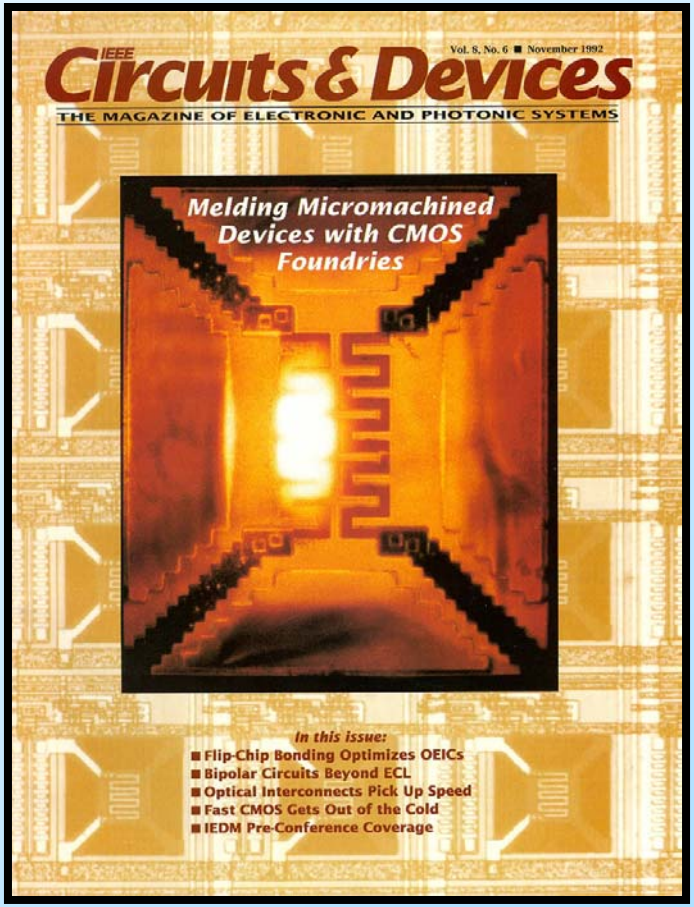
Integrate with CMOS?

- Embedded
  - Ex: Analog Devices Accelerometer
- CMOS Last
  - Ex: Sandia's IMEMS
- CMOS First
  - *cif*-MEMS

cif-MEMS: IC Design and Post-Process



cif-MEMS (*CMOS IC Foundry MEMS*)



November 1992

http://www.mosis.org/Products/mems.html

Photobit – CMOS Imager

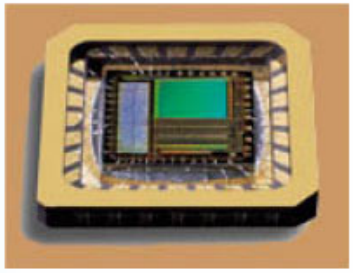
Commercial Technology: Success Stories: Photobit Active Pixel Sensor - Mozilla Firebird

File Edit View Go Bookmarks Tools Help

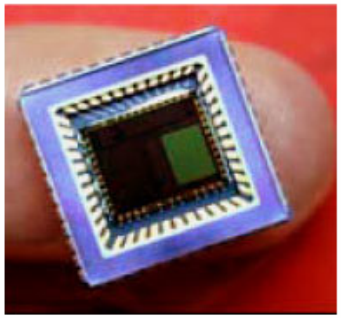
http://techtransfer.jpl.nasa.gov/successstories/computer_tech/photobit.

NIST Email

Photobit Active Pixel Sensor



Since the 1970s, when Bell Laboratories (now Lucent Technology) first developed charged coupled devices (CCD), camera and video companies have been seeking to improve the technology. CCD technology provides good image quality, but they are expensive, power hungry, and with the required accessory chips, bulky. Recognizing the shortcomings of CCD technology, and with the continuing need for lightweight imaging systems especially for interplanetary spacecraft applications, the Jet Propulsion Laboratory (JPL) began research on a second-generation solid state image sensor technology. The realization of that research occurred in late 1992 with the complementary metal-oxide semiconductor Active Pixel Sensors (CMOS APS).



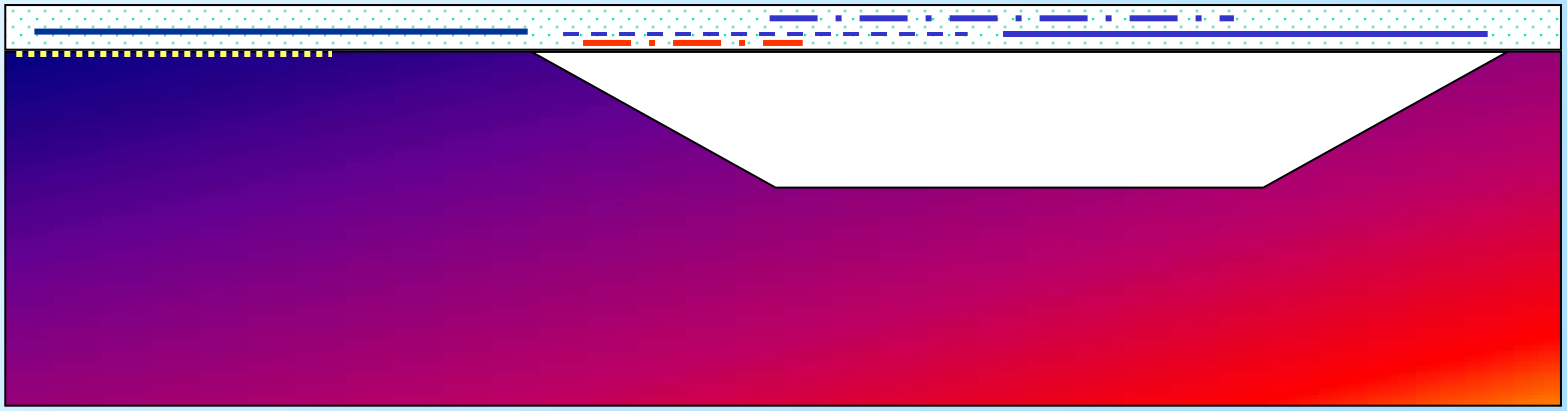
The CMOS APS expands on CCD technology in several unique ways. The CMOS APS can use the same production lines as standard semiconductors tapping into enormous economies of scale and therefore cost reductions. One chip can incorporate all the electronic controls normally requiring multiple chips. By consolidating functions and reading images more efficiently, the CMOS APS requires one-hundredth the power of a CCD system. The APS also provides JPL with a chip that not only requires less power, but is lighter and less susceptible to radiation damage in space, thereby achieving the goal of smaller, cheaper fabrications enabling affordability

Done

cif-MEMS

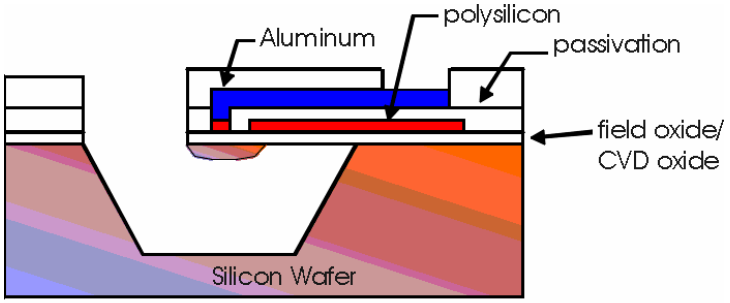
Analog/Digital Circuits Area

Silicon Micro-Machined Area

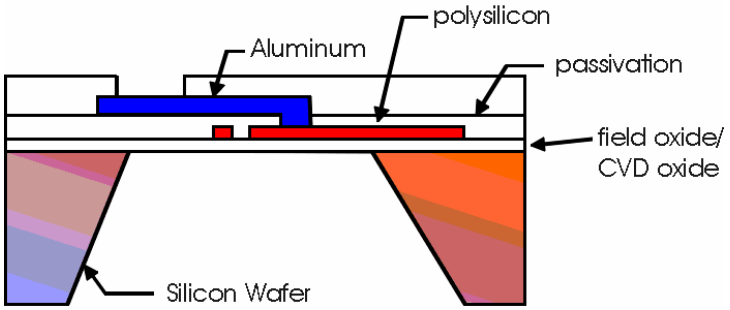


Michael Gaitan, NIST

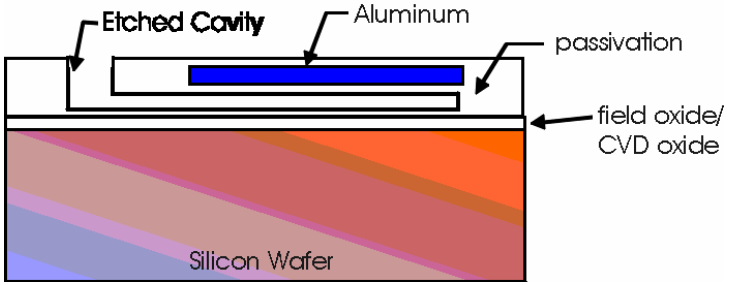
CMOS Post Processing Techniques



Top-side silicon etch



Bottom-side silicon etch



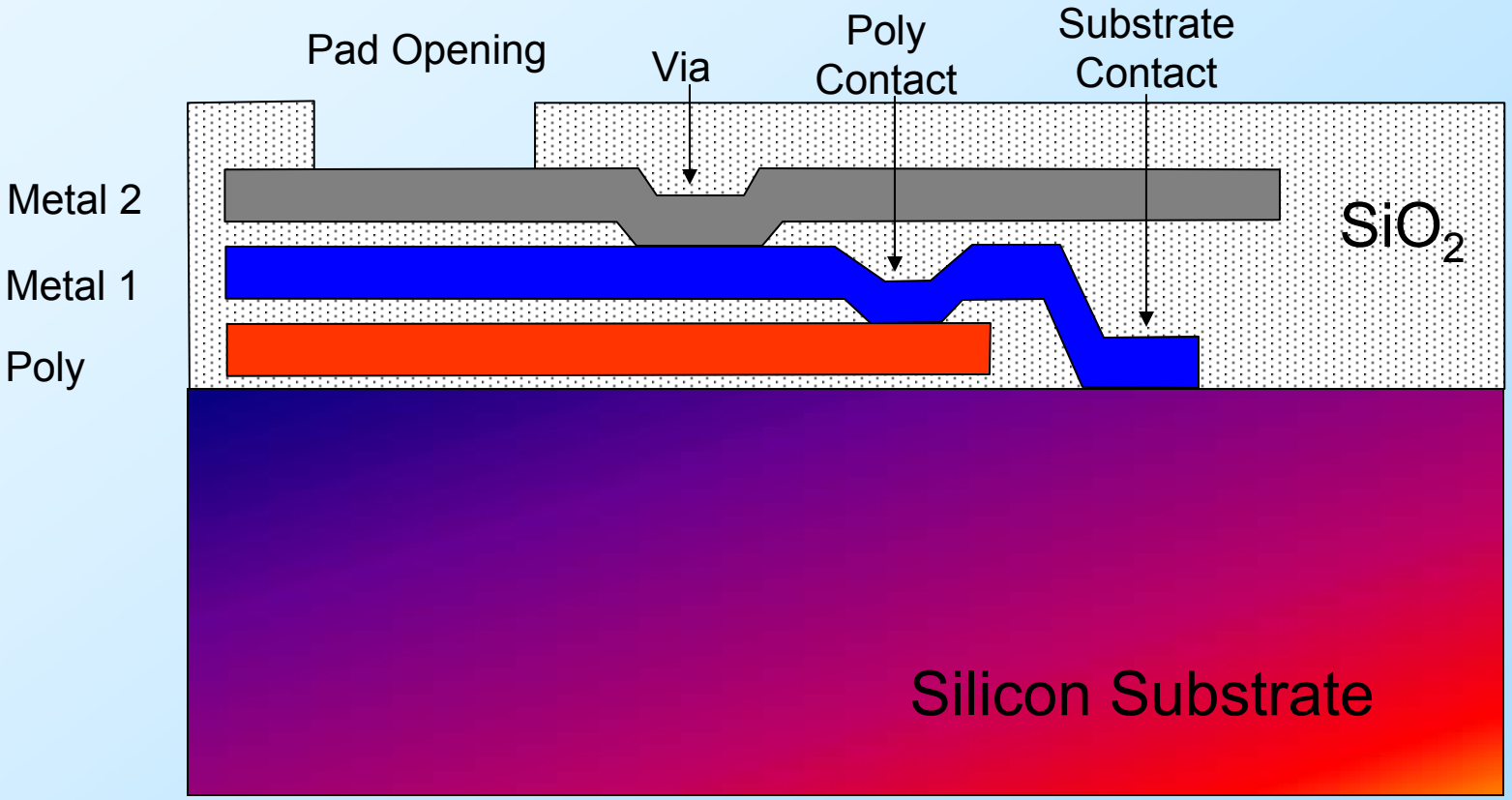
Sacrificial etch

cif-MEMS

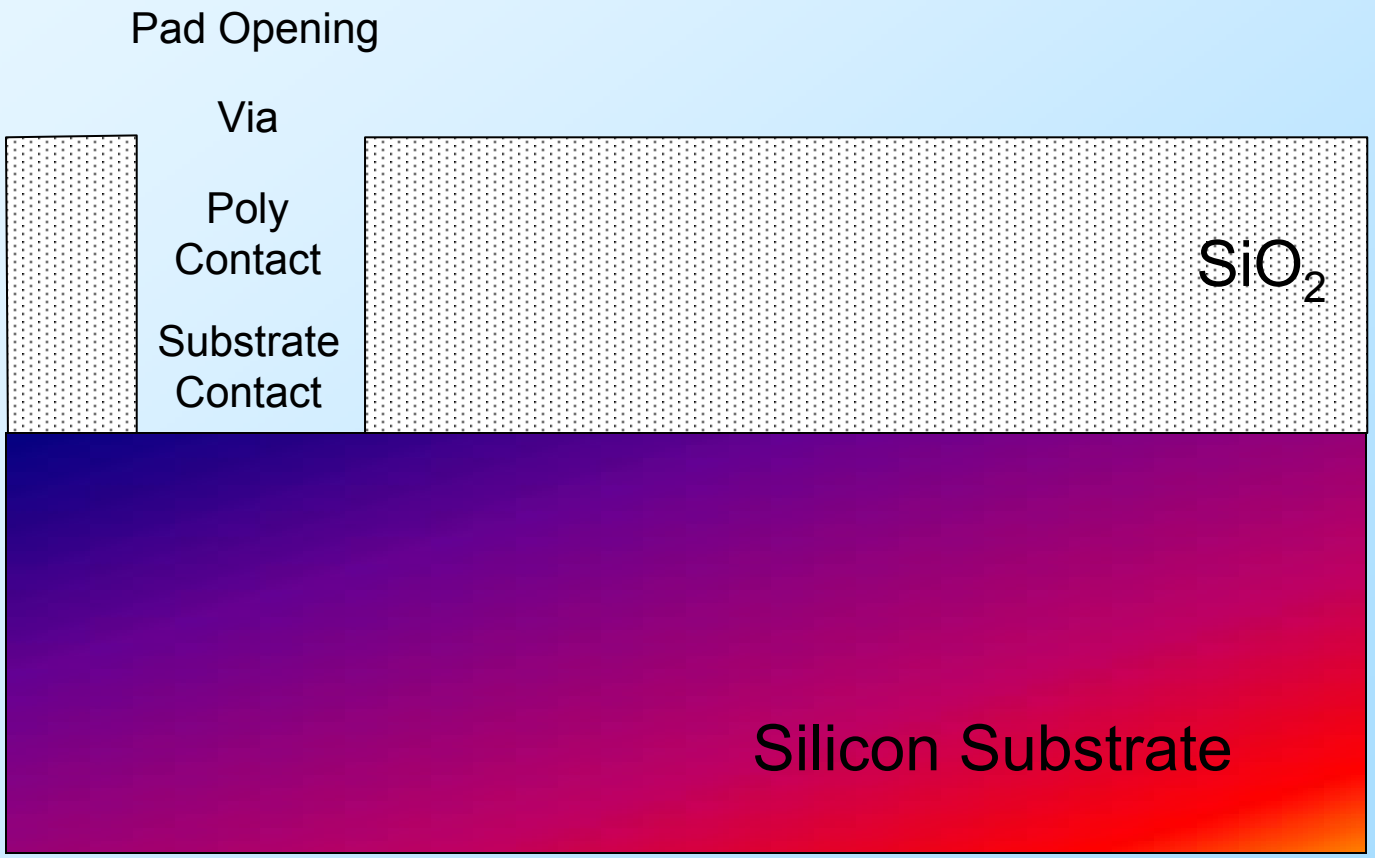
- **Elements are composed of thin films used in the CMOS process**
  - **(or deposited post-CMOS)**
- **The Micromachined Elements Are:**
  - Thermally
  - Mechanically
  - Electrically

  Isolated from the substrate

CMOS IC Cross Section

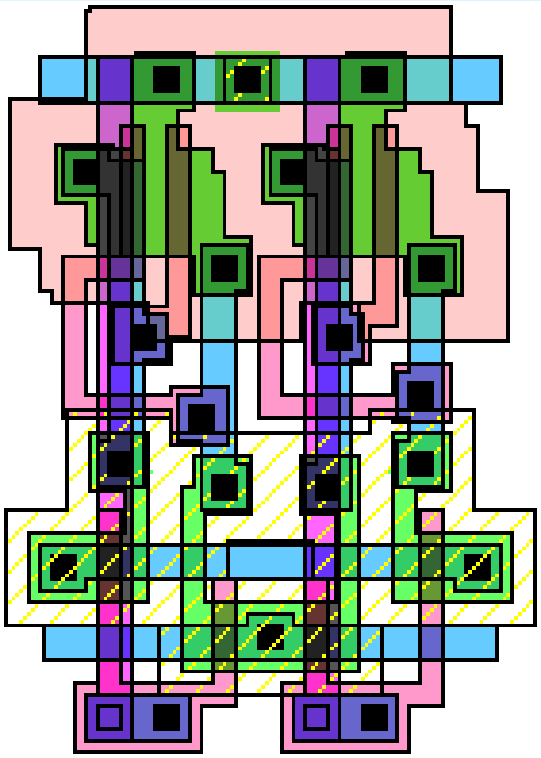


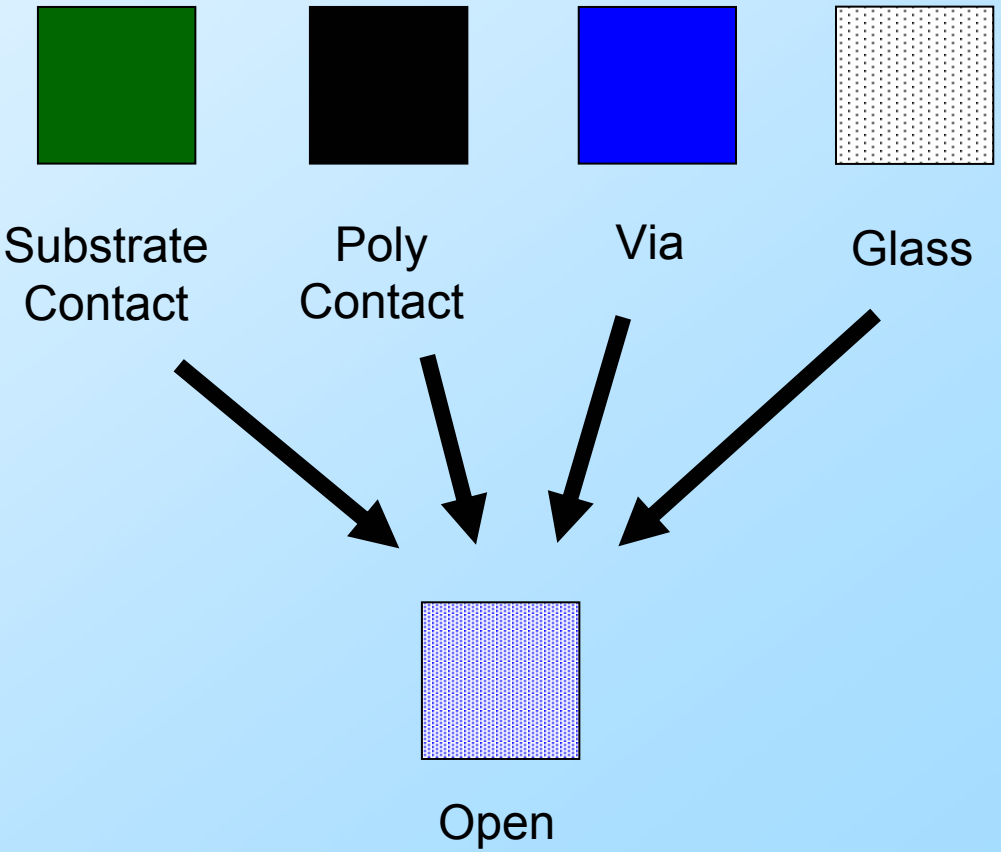
Stacked Via Open



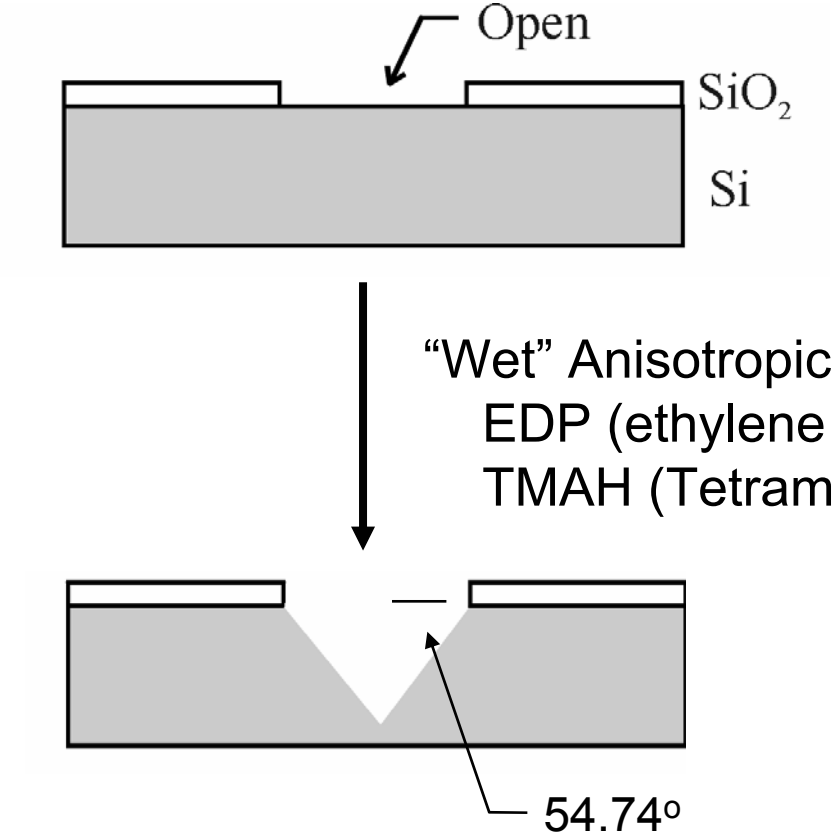
Parameswaran, et. al., *Sensors and Actuators* **19**, 289-307 (1989)

Layout

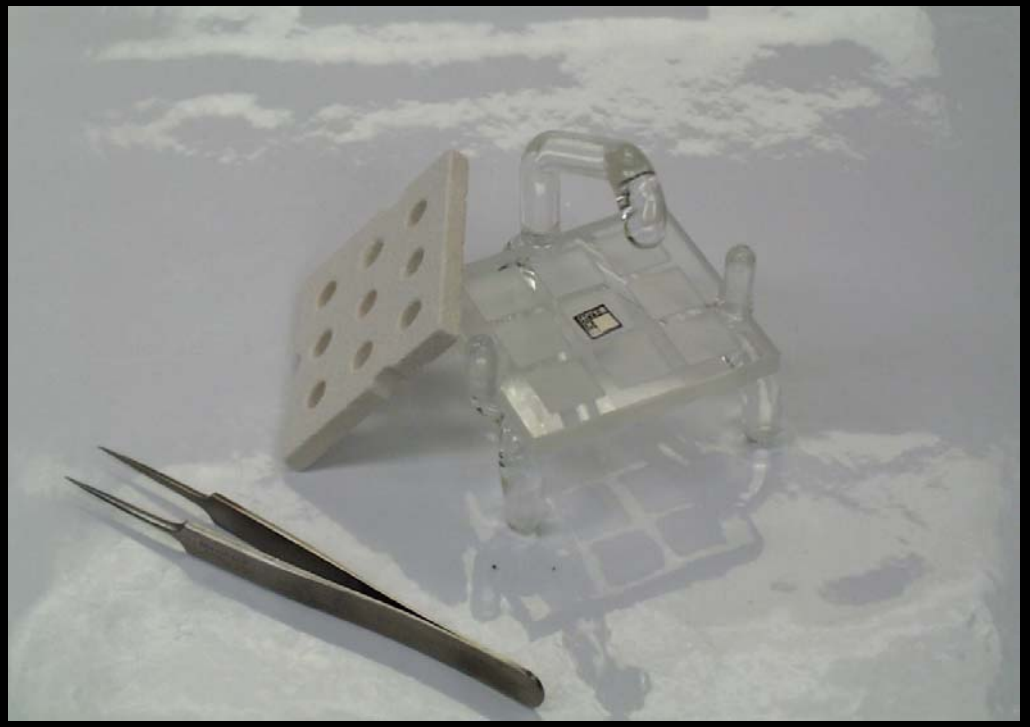




Anisotropic Si Etching



Anisotropic Etching Apparatus



Wet Anisotropic Etching

- EDP
  - Available commercially form Transene Inc. (PSE-300)
  - http://www.transene.com
- Etch Container
  - Available from Transene, Model 5000

Additional information - Fundamentals of Microfabrication: The Science of Miniaturization, Second Edition, M. Madou, CRC Press (2002)

Device Examples

- **Thermal-Based Elements**

  Thermal Displays, Microhotplate Gas Sensors, Convective Accelerometers, Flow Sensors, Vacuum Sensors, Microchemical Reactors

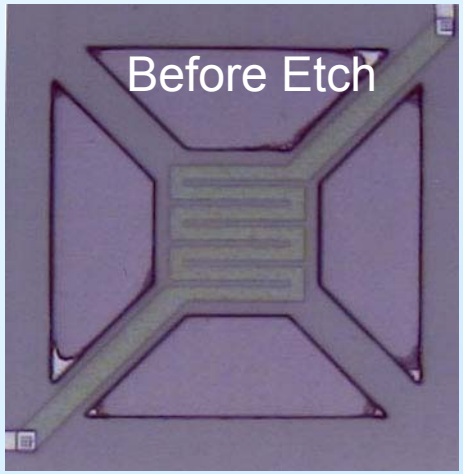
- **Microwave Elements**

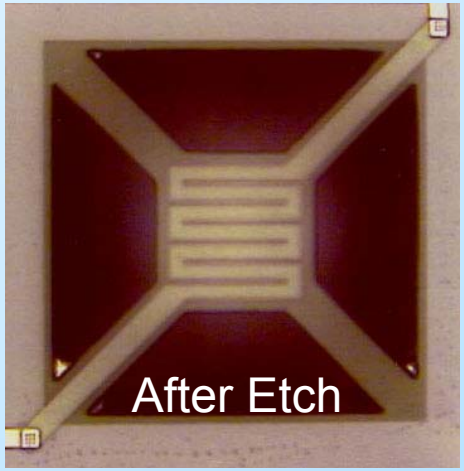
  Spiral Inductors, Coplanar Transmission Lines, Antennas, Resonant Filters, Power Sensors

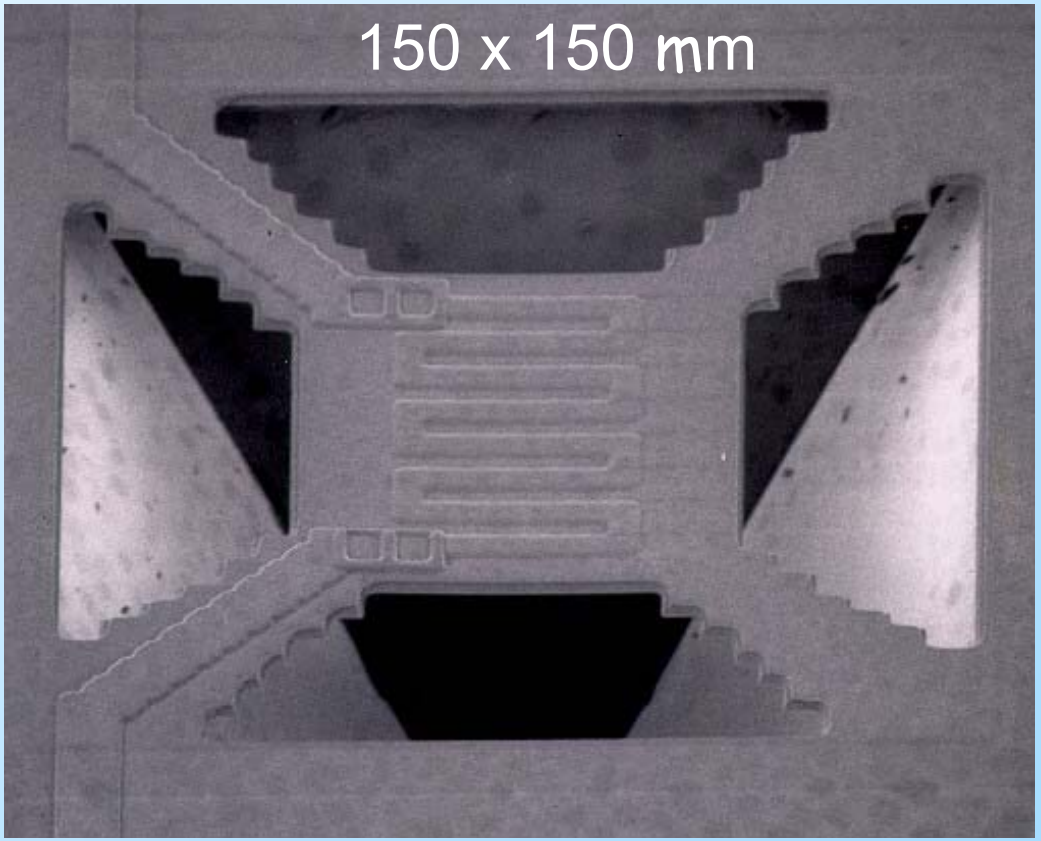
- **Electromechanical Elements**

  Resonators, Accelerometers, Micro mirrors

Example: Microheating Element

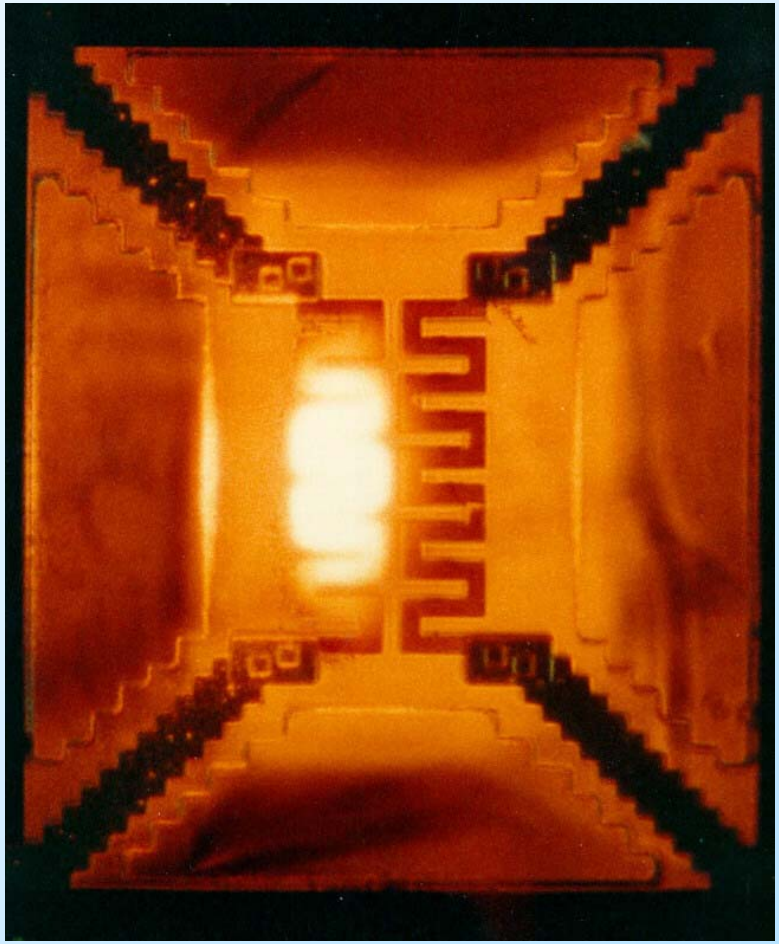


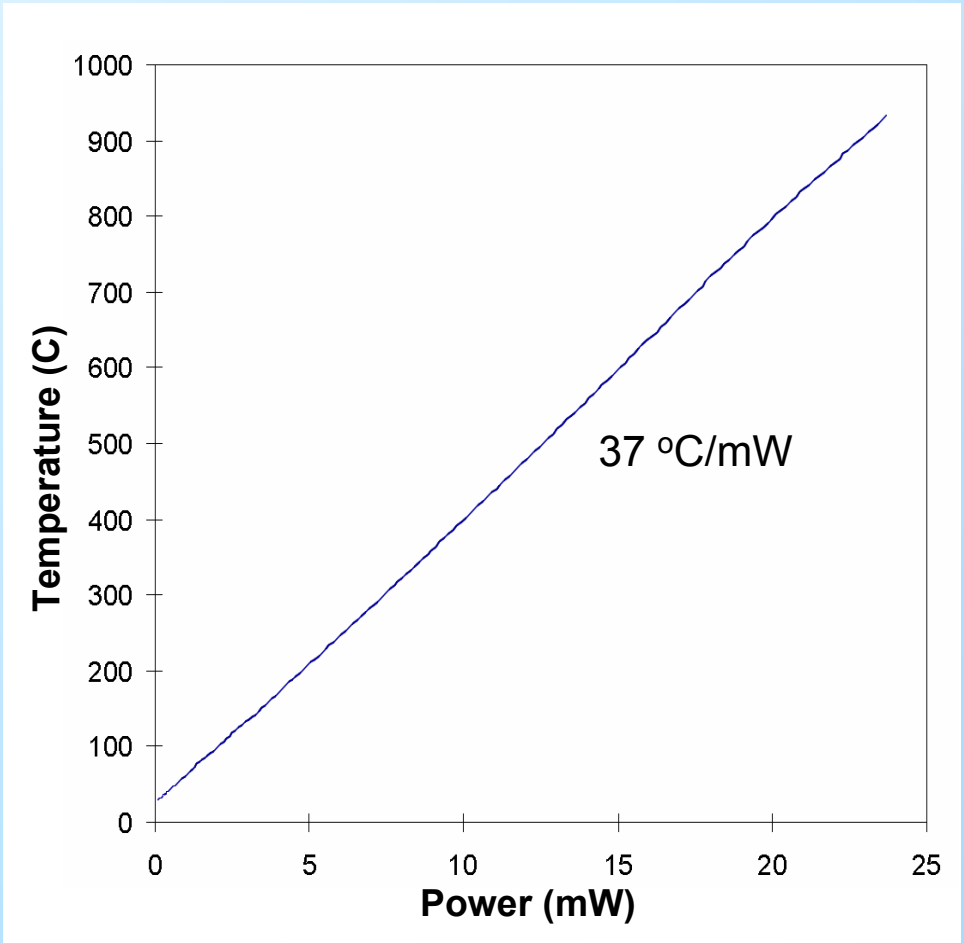




Ref: M. Parameswaran, A. M. Robinson, D. L. Blackburn, M. Gaitan, and J. Geist, “Micromachined Thermal Radiation Emitter form a Commercial CMOS Process,” IEEE Electron Device Letters, 12 (2), 57-59, February 1991.

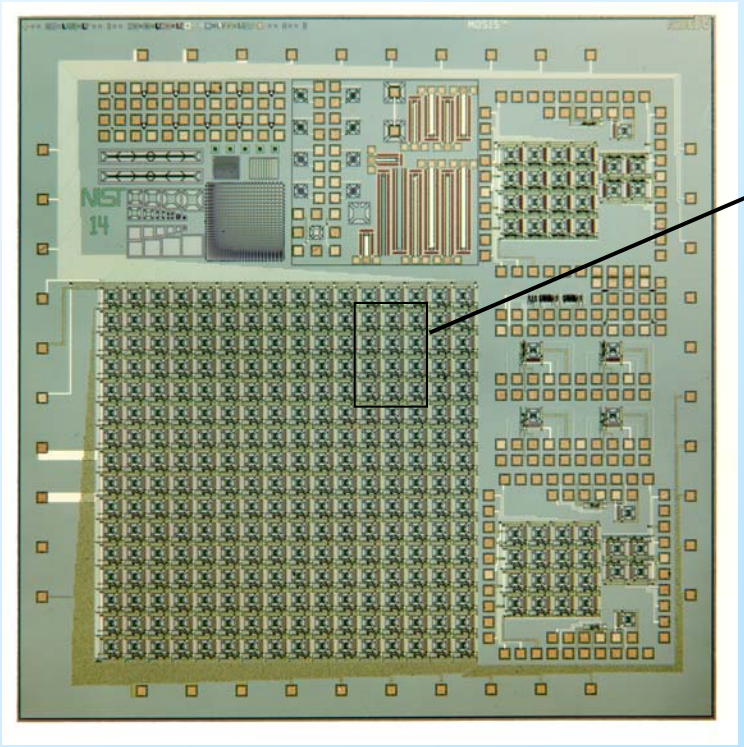
Microheating Element



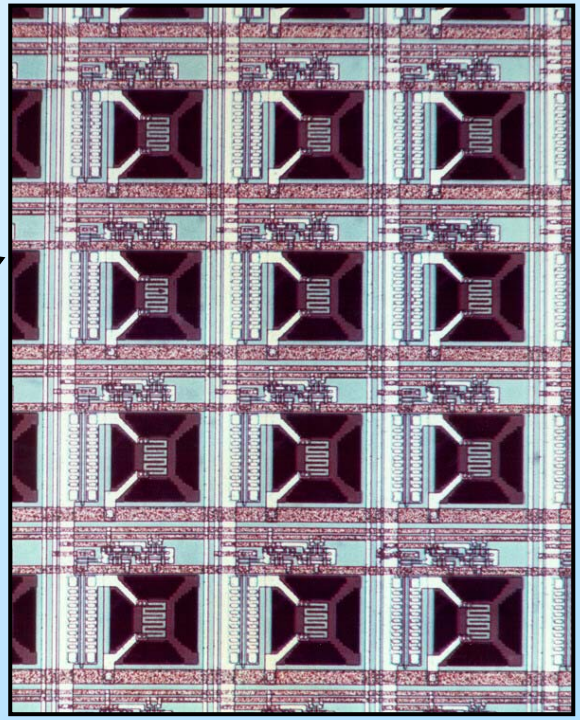


Thermal Array

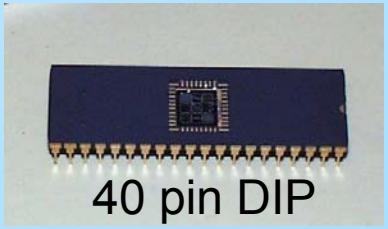
16x16 Array



6x6 mm



0.8 mm



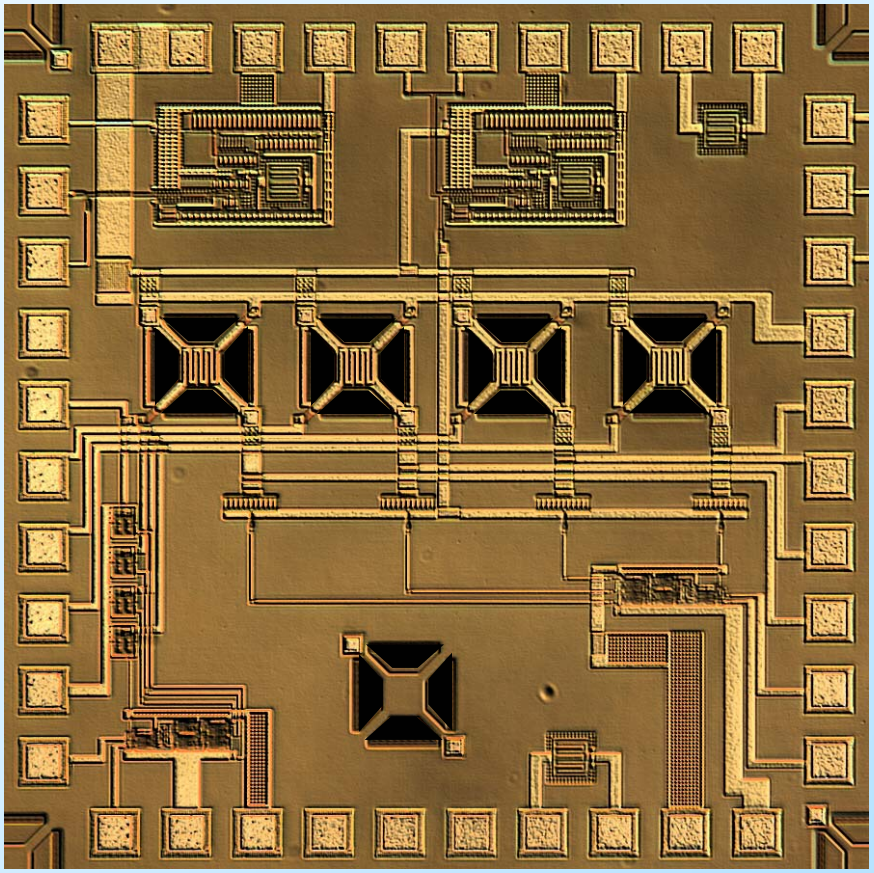
Thermal Array (16x16)

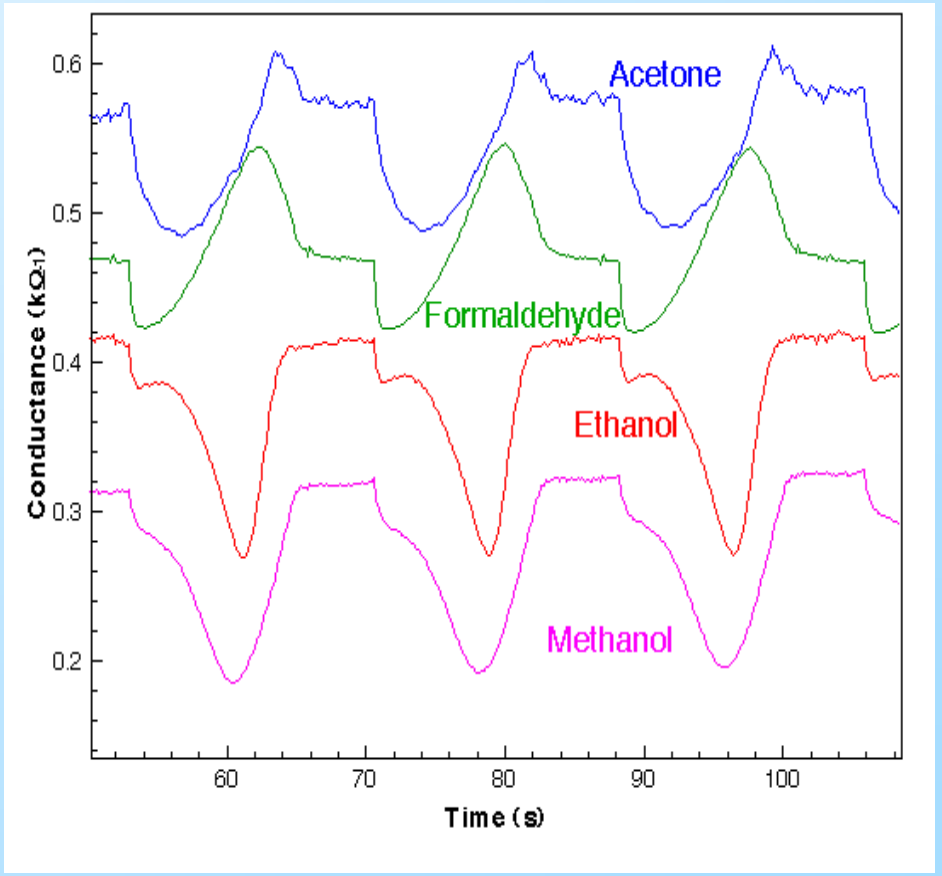
Ref: M. Gaitan, M. Parameswaran, R. Barry Johnson, and Ronald Chung, "Commercial CMOS Foundry Thermal Display," Proc. SPIE, Orlando, FL, April 1993.

Thermal Display (128x128)

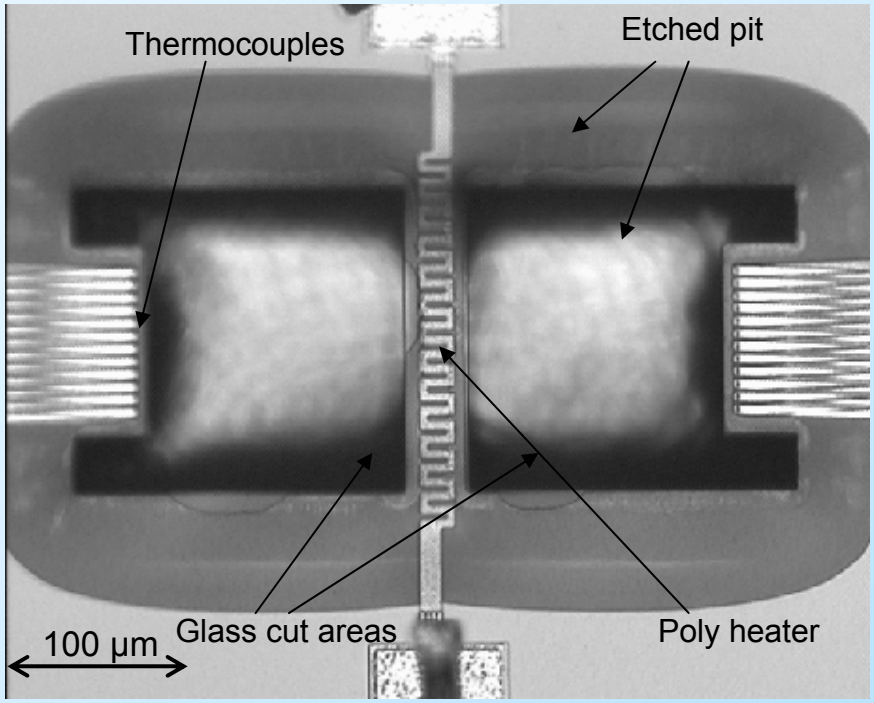
Ref: R. B. Johnson, R. Chung, and M. Gaitan, “Real-Time Infrared Scene Generation Technology and Its Application in the Test and Calibration of Infrared Sensors and Seekers,” Proceedings of GOMAC, Orlando, Florida, 145-148, March 18-21, 1996.

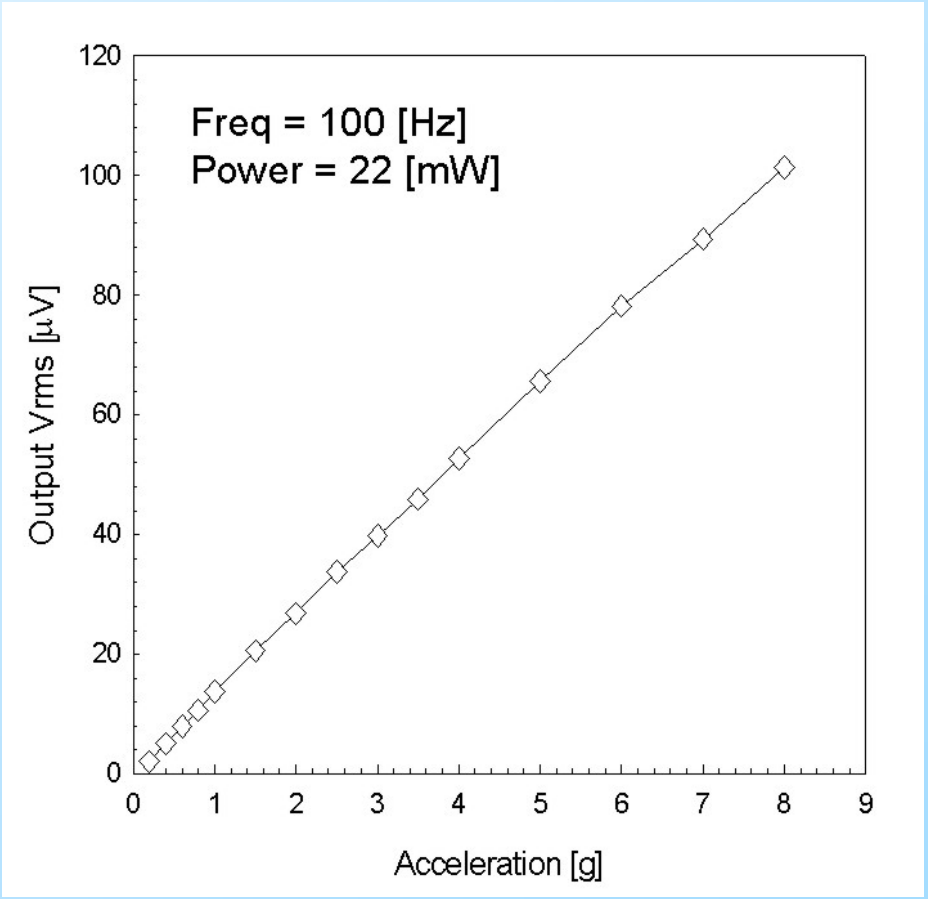
Microhotplate Gas Sensors

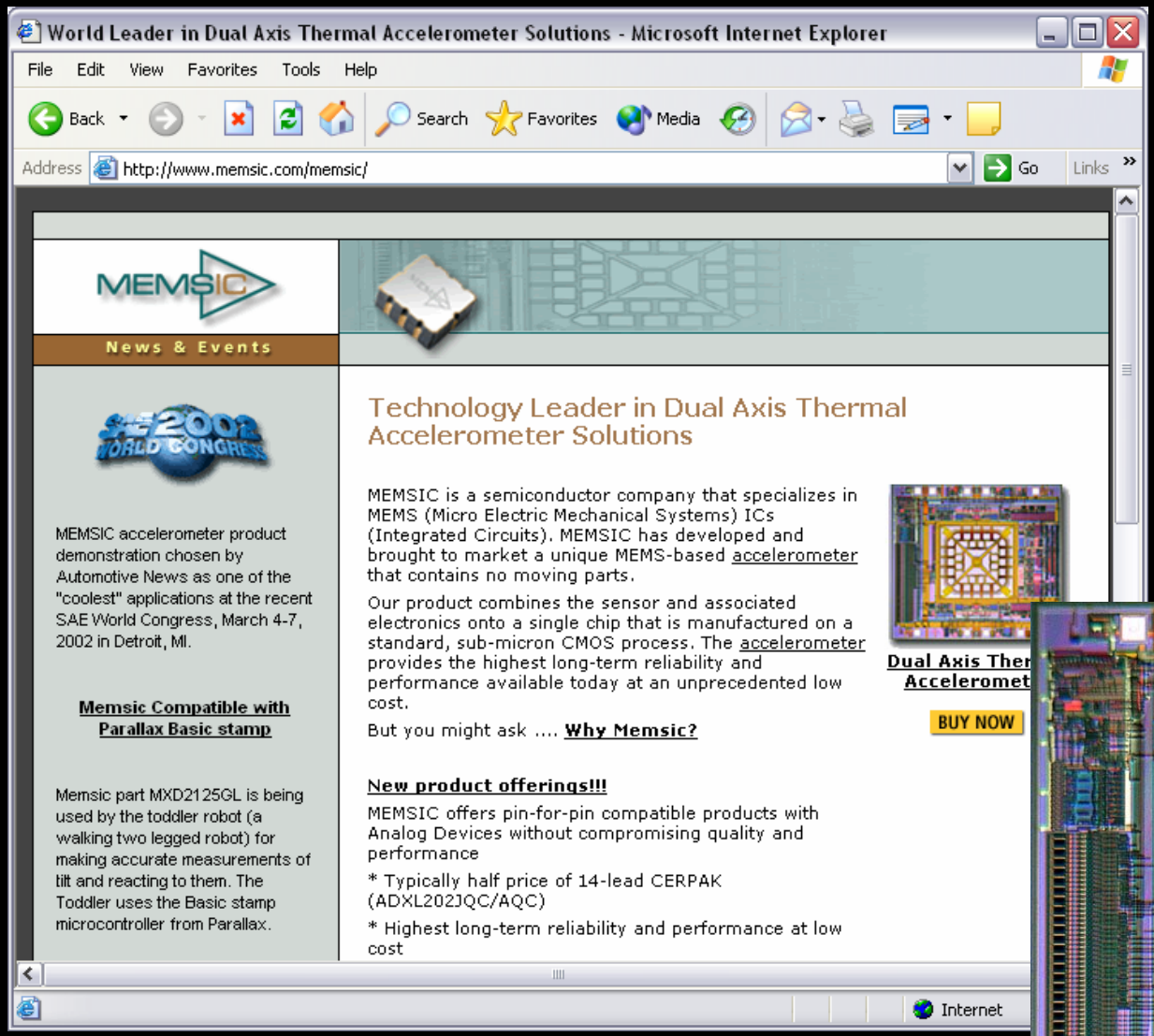


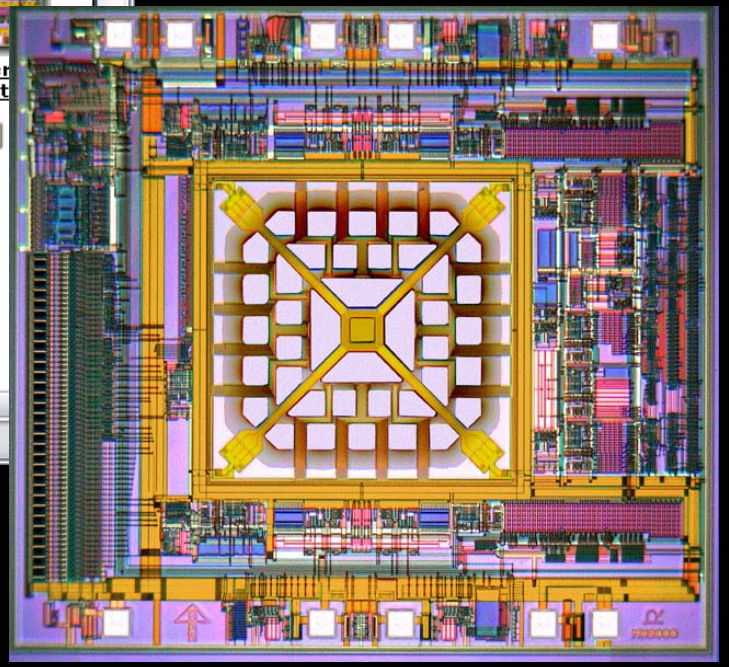


Convective Accelerometer





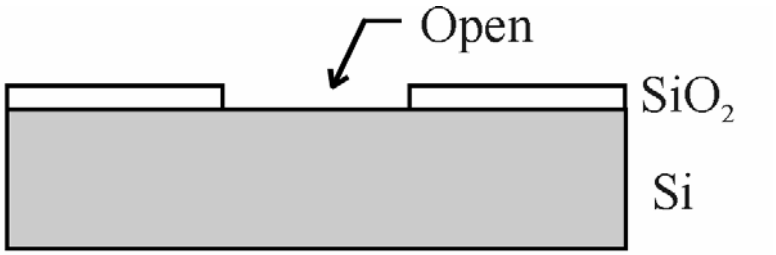




http://www.memsic.com

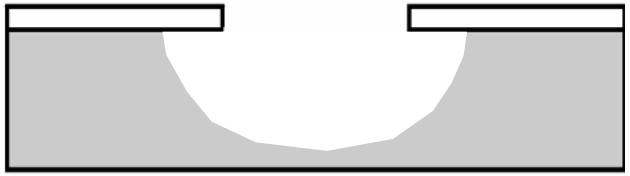
cif-MEMS

Isotropic Etching



"Dry" Isotropic Etch Step

XeF_2 (Xenon Difloride)

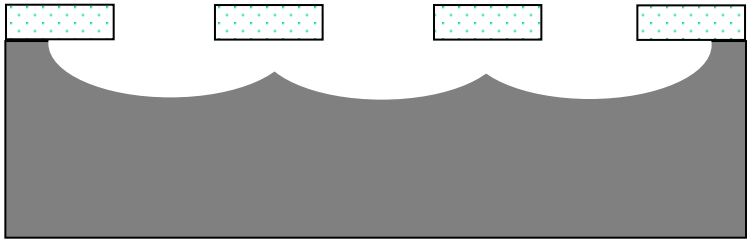


Pister Group, UC Berkeley

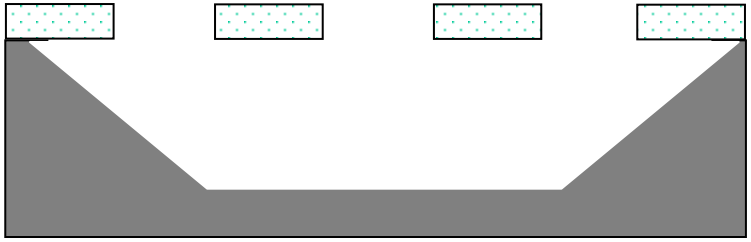
Commercial Tool: XACTIX

cif-MEMS

Hybrid Etch – Combines Isotropic with Anisotropic Etches

1. 

Isotropic Etch Step
XeF_2

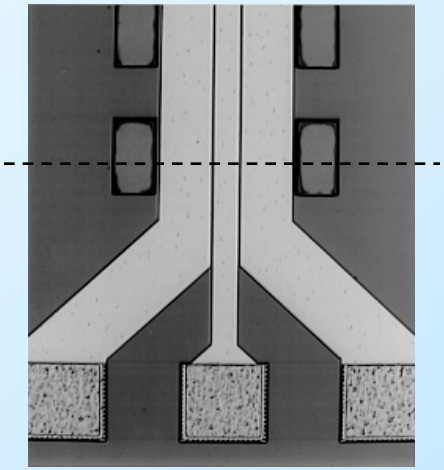
2. 

Anisotropic Etch Step
TMAH, EDP

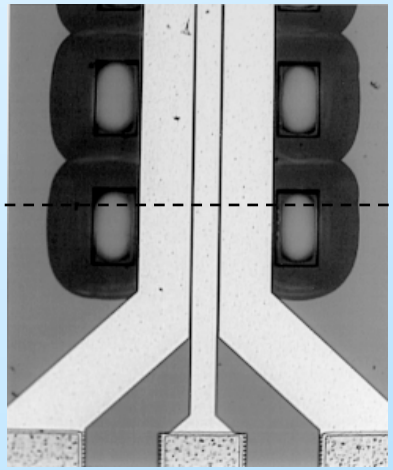
Ref: N. H. Tea, V. Milanovic, C. Zincke, J. S. Suehle, M. Gaitan, M. E. Zaghloul, and J, Geist, "Hybrid Postprocessing Etching for CMOS Compatible MEMS," Journal of MicroElectroMechanical Systems, 6 (4), 363-372, December 1997.

Example: Microwave Elements

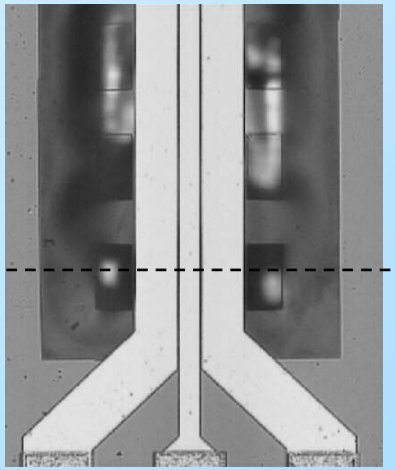
Coplanar Transmission Line (CPW)



CPW as received from CMOS process

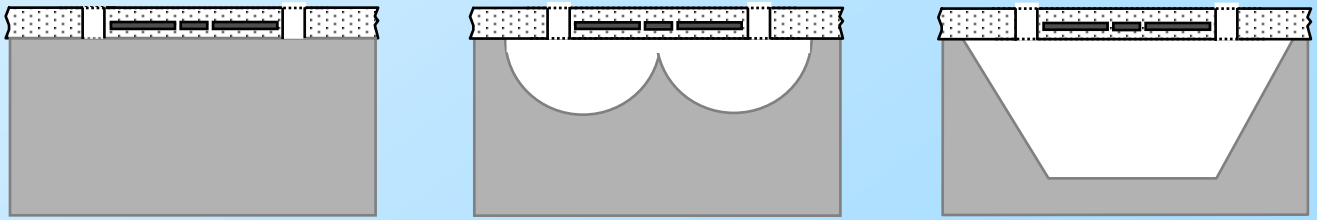


CPW after isotropic etching

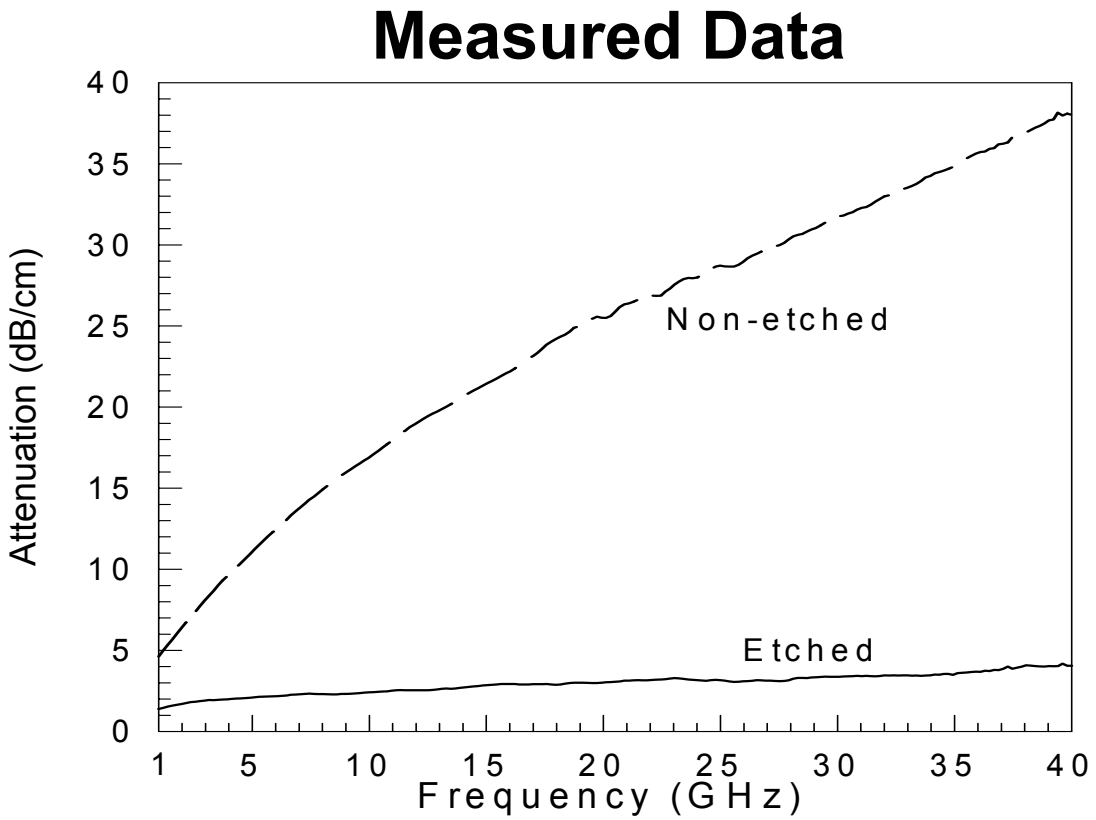


CPW after hybrid micromachining

Hybrid Etch

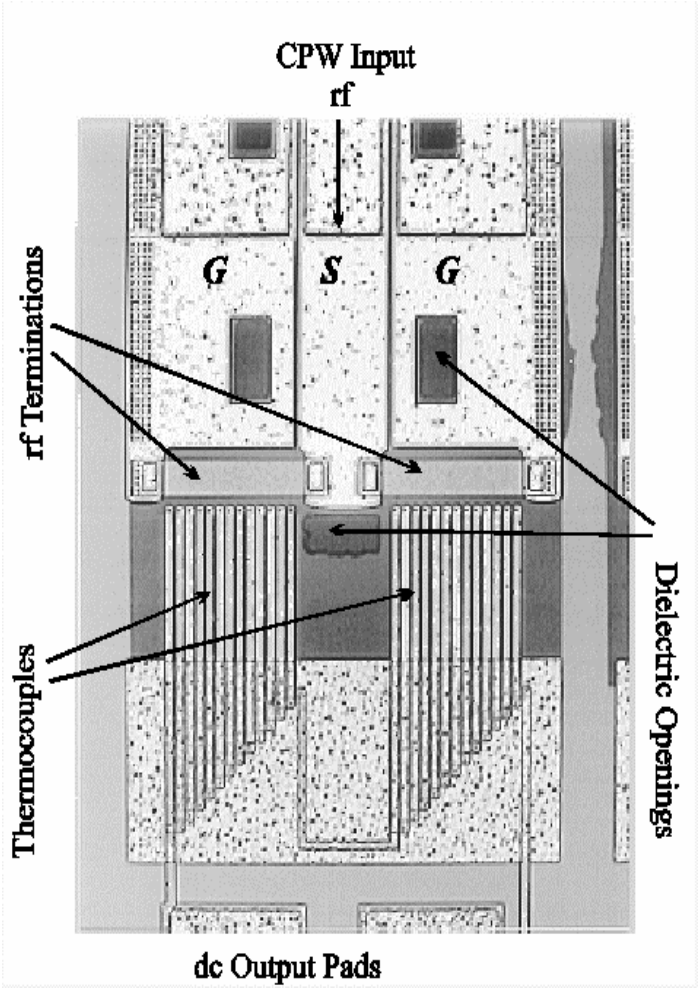


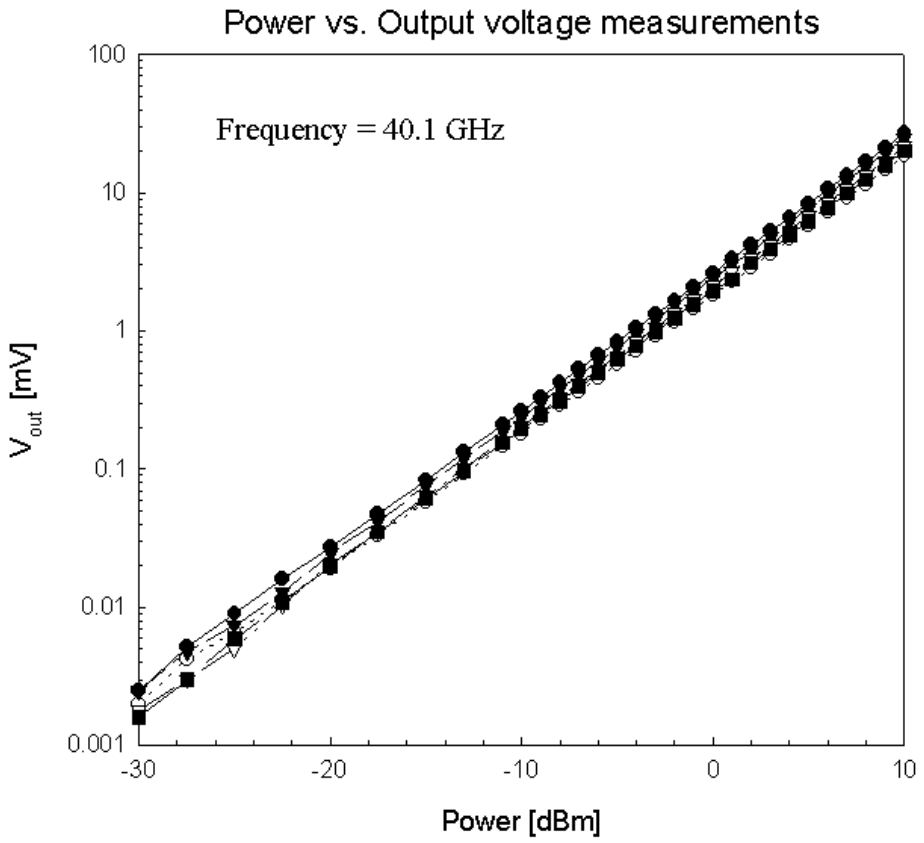
Transmission Line Characteristics



Ref: V. Milanovic, M. Igor, D. C. DeGroot, J. A. Jargon, M. Gaitan, and M. E. Zaghloul, "Characterization of Broad-Band Transmission for Coplanar Waveguides on CMOS Silicon Substrates," IEEE Transactions on Microwave Theory and Techniques, 46 (5), 632-640, May 1998.

Microwave Power Sensor





Ref:V. Milanovic, M. Gaitan, and M. E. Zaghloul, "Micromachined Thermocouple Microwave Detector by Commercial CMOS Fabrication," IEEE Transactions on Microwave Theory and Techniques, 46 (5), 550-553, May 1998.

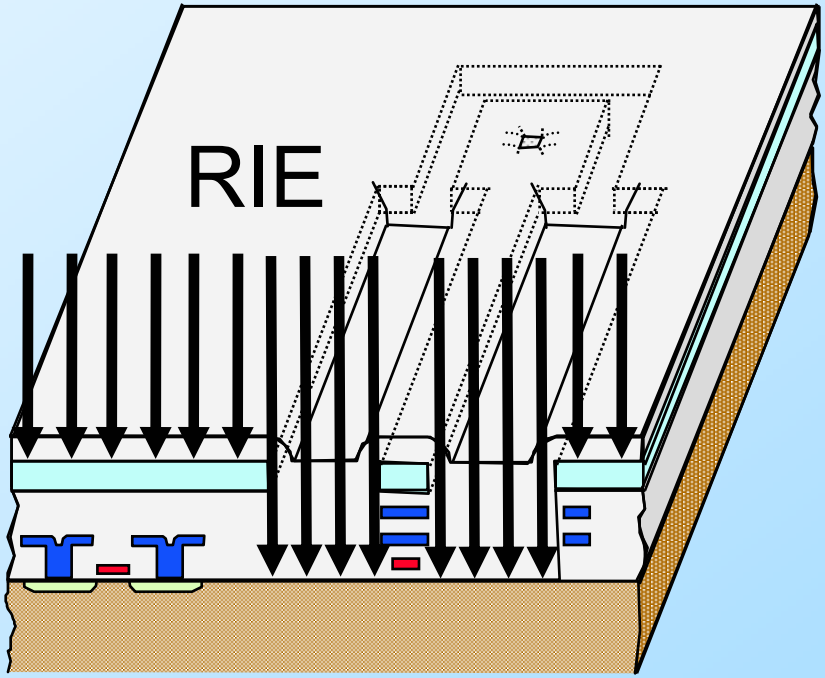
Today's Topics

- *cif*-MEMS (*CMOS IC Foundry MEMS*)
  - Stacked Via Open
  - RIE Open (ASIMPS)
- Test Structures/Standards

ASIMPS Post-CMOS Micromachining

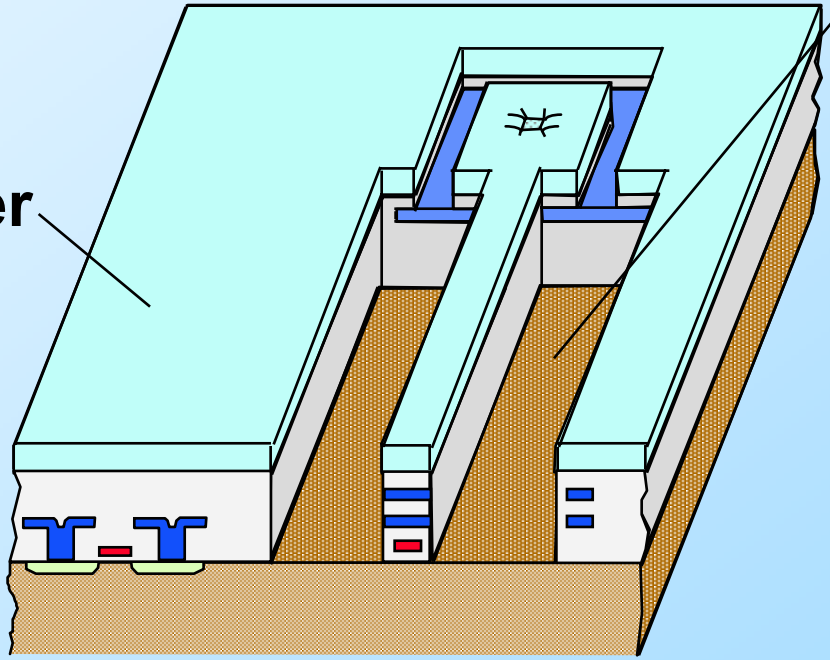
Gary Fedder, Carnegie Mellon University (CMU)

Application-Specific Integrated MEMS Process Service



G. Fedder *et al.*, Sensors & Actuators A, v.57, no.2, 1996

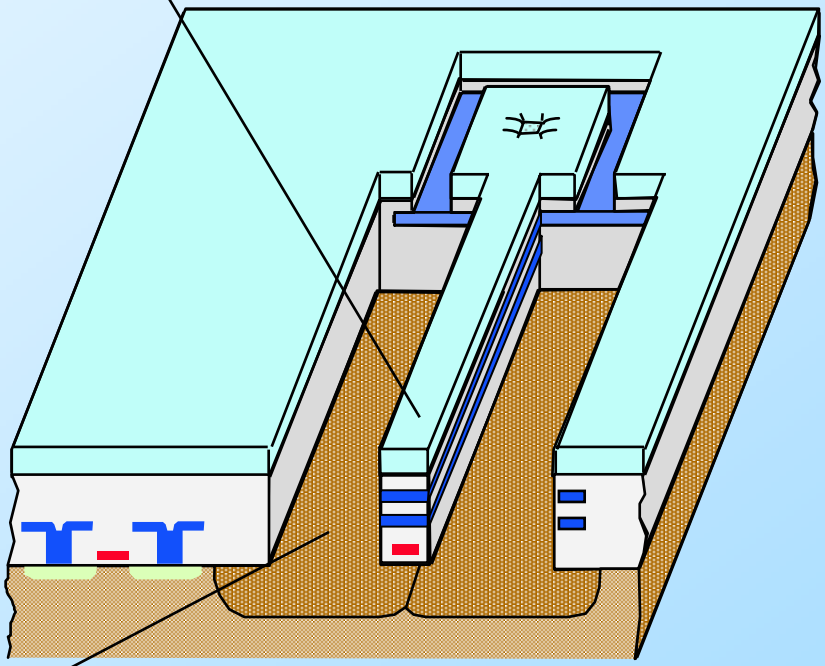
ASIMPS Post-CMOS Micromachining



G. Fedder *et al.*, Sensors & Actuators A, v.57, no.2, 1996

ASIMPS Post-CMOS Micromachining

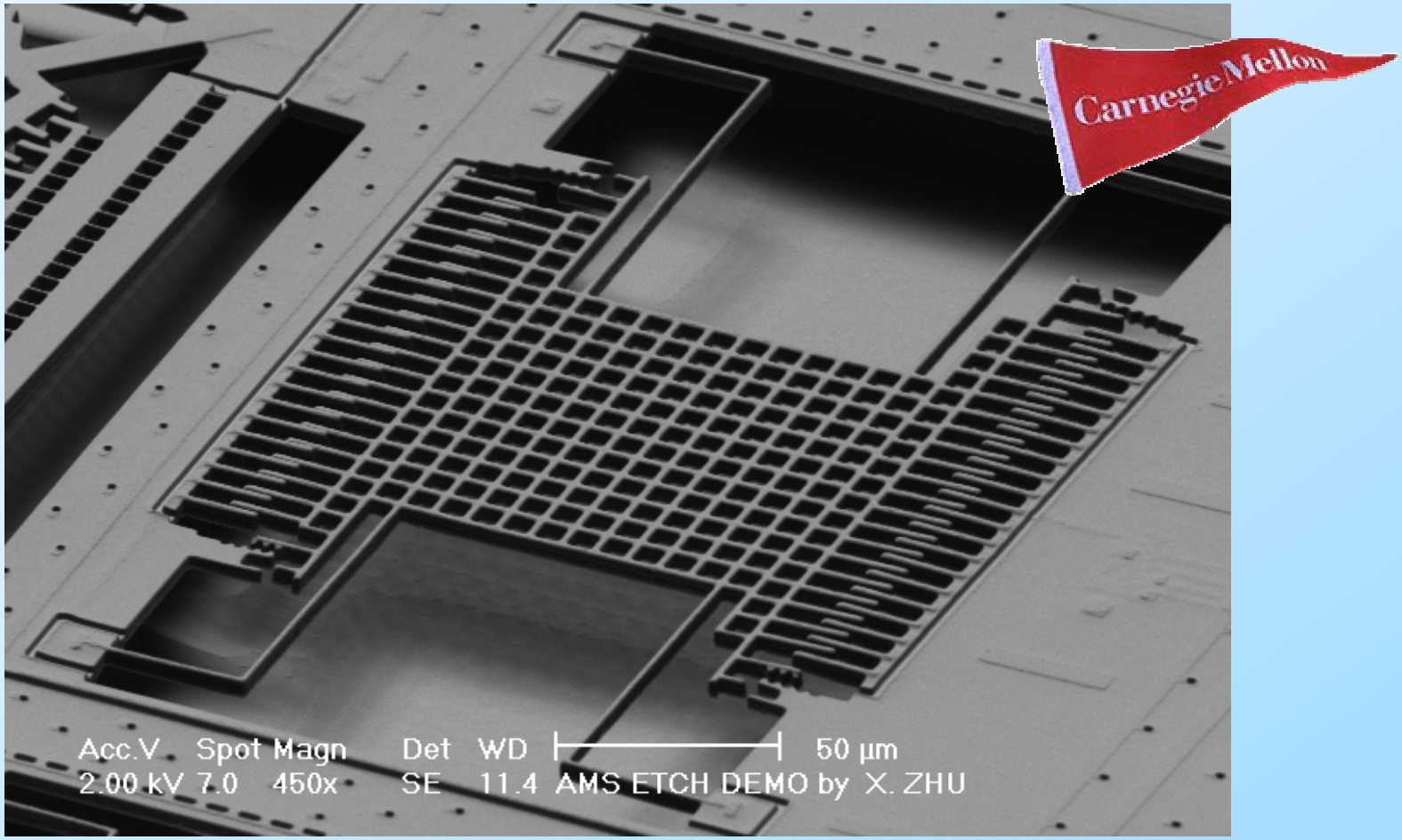
Composite beam



Anisotropically Ecthed Pit

G. Fedder *et al.*, Sensors & Actuators A, v.57, no.2, 1996

ASIMPS Post-CMOS Micromachining



ASIMPS: AMS 0.6 mm, 3-metal

http://www.ece.cmu.edu/~mems/projects/asimps

Today's Topics

- *cif*-MEMS (*CMOS IC Foundry MEMS*)
  - Stacked Via Open
  - RIE Open (ASIMPS)
- Test Structures/Standards

Test Structure Standardization

Task Group Descends On Micro-Technology

An ASTM task group is working with tiny mechanical parts smaller than the width of a human hair. Work on microelectromechanical systems (MEMS) standardization is under way in Task Group E08.05.03 on Structural Films and Electronic Materials, under Subcommittee E08.05 on Cyclic Deformation and Fatigue Crack Formation, in Committee E-8 on Fatigue and Fracture. Scientists experienced in fatigue and fracture and/or creep-process are sought for development of MEMS test methods.

In these tiny systems, barely visible gears, hinges, motors, and other mechanical components are manipulated by micro-tweezers and probes, and viewed with scanning electron microscopes. "Imagine everything in day-to-day life being miniaturized: gears, wheels, motors, turbine engines, everything. My whole fatigue testing machine fits on a silicon chip a few hundred microns square," said Task Group Chairman Chris Muhlstein, a materials scientist in the Materials Science and Engineering Department, University of California, Berkeley.

MEMS are made from combinations of metals, ceramics, and polymers. "The little nozzles on your ink-jet cartridge are probably one of the

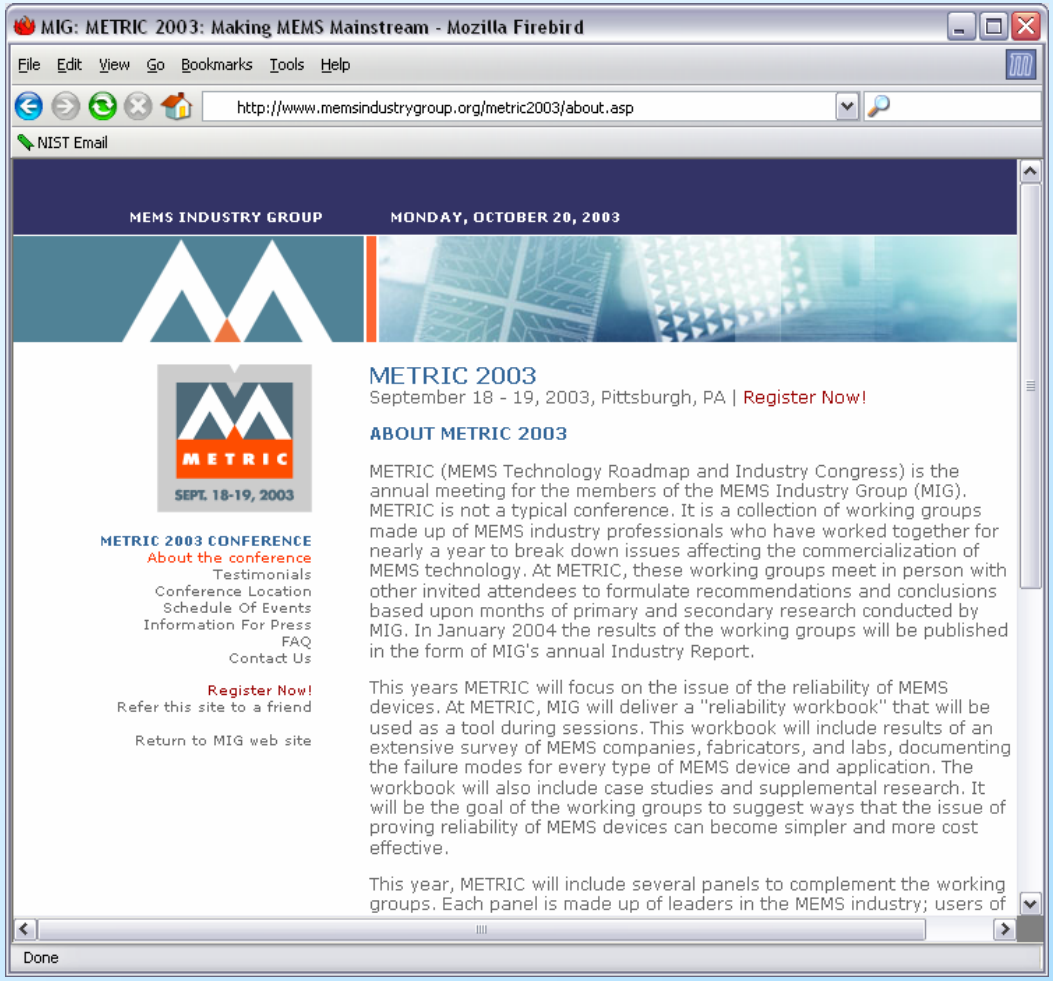
(CONTINUED ON NEXT PAGE)

COURTESY OF SANDIA NATIONAL LABORATORIES

Smaller than the width of a human hair, microscopic gears of this type are used in polysilicon microengine transmissions, an important application for new ASTM standards.

- ASTM (American Society for Testing and Materials) Task Group E08.05.03 established in 1998
- Activities
  - Residual Stress Standard Test Method (Round Robin in Progress)
  - Elastic Modulus Standard Test Method

MEMS Industry Group



METRIC 2003 Reliability Workshop

Held in Pittsburg PA
Sept 2003

SEMI: International MEMS Steering Group (IMSG)

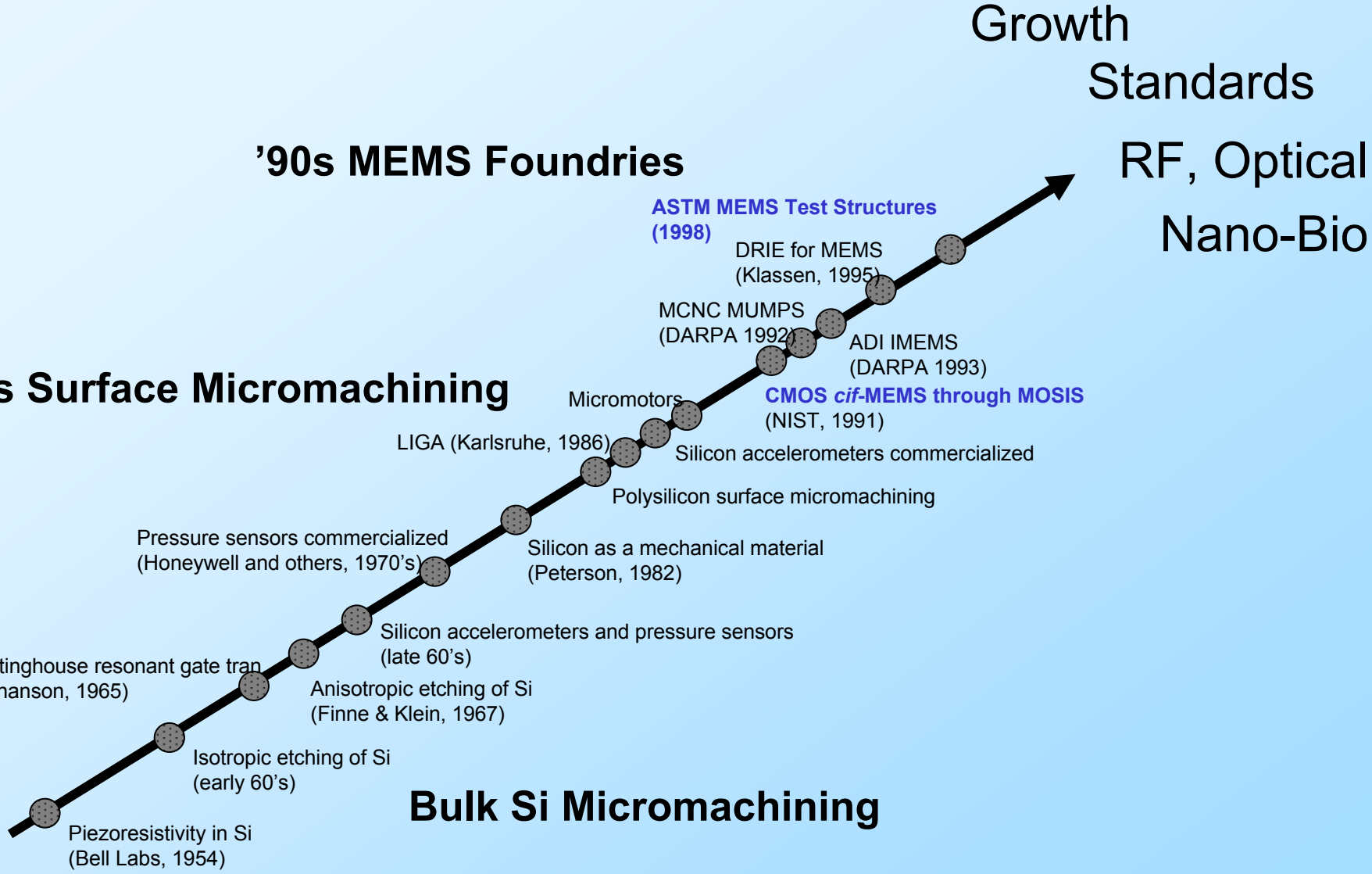
Equipment Industry Group

Upcoming Workshops

Boston:
Spring

SEMICON West:
Summer

MEMS Technology Timeline



Summary

- *cif*-MEMS is a Path to CMOS Integration
  - ASIC → *cif*-MEMS
  - Compatibility with IC foundry fabrication
  - Cost effective
- Interest in Standards is rapidly growing
  - We need your help